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Manatū Mō Te Taiao

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Application 4176

SMALL LANDFILL CLOSURE CRITERIA

RISK ASSESSMENT FOR SMALL CLOSED LANDFILLS

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EXECUTIVE SUMMARY

This report presents a method of Risk Assessment for Small Closed Landfills (RASCL) and is the result of research funding from the Ministry for Environment, Sustainable Management Fund, Project 4176. Risk components specific to small landfills have been identified in accordance with the New Zealand standard for risk assessment[1], and the assessment methodology is based on the Risk Screening System (RSS) developed for the Ministry for the Environment[2]..

The main hazards due to small, closed landfills comprise:

- groundwater contamination,
- surface water contamination,
- gas (landfill gas or toxic gas), and
- surface exposure (ingestion or physical harm from sharps).

The risk of each hazard is a function of the contaminant source, containment, transport pathway and the receptor. Matrices to assist in weighting values for analyses of each of the risk components have been developed specifically for small closed landfills. This means that for any small, closed landfill the risk due to each hazard can be assessed and ranked high, medium or low.

The RASCL method has been validated through comparison of real data from 12 existing small, closed landfill sites. The assessment results suggest that small landfills present a low risk to the environment and health in general, and this was confirmed by comparison of the monitoring data against relevant standards. This is logical since by definition small landfills are of reduced surface area and volume. This means that leachate is generally in low concentration, and the risks to the environment and health are correspondingly low. However, it has been recognised there is a constraint to the method, that by using the default value suggested for size, it does not allow for any site to be categorised as high risk.

The RASCL method is considered a useful tool to identify priority sites where further investigation may be required, especially in the event of changes in land use. It is suggested that Councils maintain a “live register” of small closed landfills that should be available to the public and re-assessed as required.

1 Introduction

1.1 Background

Small landfills have historically grown out of uncontrolled tipping, or in areas where demand, population density or engineering resources are less than in more developed areas. Small landfills are therefore often unique in the type and volume of waste, their location and low level of engineering compared to larger landfills. This research project focuses on small closed landfills, which have been defined as being less than 15,000 m^3 in volume[3]. The number of such sites in New Zealand is unknown and often the level of information about relatively well known sites is limited.

The aim of the project was to develop a practical method to assist district and city councils to identify the environmental risk from small closed landfills. The approach taken has been to develop a semi-quantitative risk assessment method based on a hazard/pathway/receptor risk model. This allows individual hazards at each site to be ranked (high, medium, and low), and individual landfills to be ranked against each other.

Ranking landfill sites allows Councils to set priorities, target monitoring, implement appropriate management plans and improve sustainable management of the environment. Once the sites have been categorised, Councils can develop a register of sites, and prioritise action consistent with the policies incorporated within New Zealand's Waste Strategy[4].

The proposed assessment method is based on the Australian and New Zealand Risk Management Standard[1], and the following Ministry for the Environment publications:

- Draft National Rapid Hazard Assessment System for Potentially Contaminated Sites[5]
- A Guide for the Management of Closing and Closed Landfills in New Zealand[3].
- Landfill Risk Screening System Methodology[6],
- Risk Screening System (RSS) for Contaminated Sites[2].

1.2 Project Outcomes

The outcomes of this project are:

1. A methodology to assess risk to the environment from small closed landfills under various climatic and environmental conditions.
2. Verification of the method using groundwater and surface water monitoring data from existing small closed landfills.

The main beneficiaries will be:

1. Territorial Authorities – The risk assessment procedure is robust and applicable to small landfills nationwide. Councils will have an objective and defensible basis on which to screen landfills, and to gain an indication of the level of risk (high, medium or low) at each site.
2. Territorial Authorities, Government Bodies, Developers and Consultants – An outcome from the risk assessment should be a database held by Council. This is expected to be useful for all parties undertaking environmental work, or land development.

2 Review of Existing Risk Assessment Methods for Contaminated Sites

In determining suitable criteria to adopt for a risk assessment, it is necessary to review existing risk assessment methodologies. The Draft National Rapid Hazard Assessment System for Contaminated Sites[5] provides a generic methodology for assessing hazard, based on a pathway/receptor model. However, it requires a high level of detail, which is not available for most small closed landfills.

The Risk Screening System (RSS)[2] simplifies this approach to allow a semi-quantitative assessment of contaminated sites. The RSS specifically evaluates the risk to three receptors (groundwater, surface water and direct contact) by way of a weighting system. This semi-quantitative approach does allow comparisons between sites, but by definition does not result in an actual quantitative risk value[1].

Neither of these methods have been specifically developed for landfills. While guidelines for management of closed landfills[3] indicate what information is required to perform a risk assessment, and the potential source of information, they do not provide a risk assessment methodology. Guidelines for semi-quantitative assessment of the risk from operating landfills[6] are currently being developed by the Ministry for the Environment.

3 Risk Assessment for Small Closed Landfills (RASCL)

There is often very little information about small closed landfills. A typical closed landfill is likely to be poorly capped, have no lining and often be close to, or within a water body. The landfill may have been closed for a long period of time, and local knowledge of the operation or characteristics of the landfill (e.g. depth, geology, and type of waste) may have been lost.

Given the paucity of data, an effective practical approach to assess environmental risk at a small closed landfill is to undertake a screening analysis based on inputs that can be directly observed, or determined from existing information (such as topographical maps, bore logs, water quality databases, soil maps and aerial photographs). Rigorous application of this type of procedure will allow Councils to compare individual sites, to rank them in terms of risk and to semi-quantify the degree of risk. This will, in turn, allow resources to be allocated in a logical manner to address areas of perceived need.

The risk assessment methodology developed for this study is based on assessment principles described in the NZ standard for risk assessment[1], and on the RSS[2]. The methodology is graphically illustrated as matrix flow charts in Figures 1-4. These should be consulted to assist with understanding the methodology.

3.1 Hazard and Risk Identification

The first step in applying the RASCL method is to identify the potential hazards. The key hazards associated with landfills as identified in the RSS are:

- Contamination of groundwater,
- Contamination of surface water,
- Gas accumulation, and
- Direct exposure to contaminated soil, sharp objects or hazardous gases.

The risk due to each hazard is a function of the probability of occurrence, and consequence of occurrence. For small closed landfills, probability and consequence are a function of:

- Contaminant source
- Containment

- Transport pathway, and
- Receptor model.

3.1.1 Containment Source Default Values

a) Quantity/size

Based on the RSS, the default value for the quantity of a contaminant from small landfills (less than 15,000m^3) is 0.4. This reduces the possible risk to low or medium (see Section 3.7) using the methodology presented in Figures 1 to 4.

b) Mobility

All leachate and gas is assumed to be of similar high mobility and is assessed as 1.0. The default value for surface exposure is assumed to be 0.2 (Figures 1 to 4)

c) Toxicity

Weightings for contaminant toxicity will depend on the exposure pathway e.g. green waste may not have high concentrations of metals in the leachate, but may generate significant volumes of gas. Therefore the weighting for toxicity is given for each hazard (Figures 1 to 4). Toxicity of leachate from hard fills and green fills is likely to be low, while industrial waste may have highly toxic components. The main variables between sites are the age and type of waste, and these are the major factors which affect toxicity. The criteria used in the Closed Landfill Guidelines[3] for the age and type of waste are used here.

d) Lining/Containment

It is expected that most sites will have no engineered lining and therefore will default to 1 (Lining, Figures 1 to 4).

3.2 Risk to Groundwater

3.2.1 Assessment of containment parameters

Protection of aquifer and effectiveness of capping

The ability for leachate to enter the groundwater system is a key factor for contaminants to become mobilised into the environment. Analysis of the likelihood for this to occur has been considered through an assessment of the permeability and thickness of the materials underlying the landfill, assessment of the likely groundwater level at the site, and the likely effectiveness of the landfill cap (Figure 1).

Groundwater is well protected against contamination from leachate if the materials underlying the site are fine grained (impermeable), and deposited as a thick (metres) sequence. The degree of protection is generally less (or may be negligible) if materials are coarse grained (free draining), or where low permeability materials have been deposited in thin layers or have been disturbed through geological processes such as faulting.

In addition, consideration of likely groundwater levels is also important. Some landfills intercept the groundwater surface, either permanently or intermittently when the groundwater rises after heavy rain or during the winter months. Other landfills may be located in clean gravel of high permeability with interbeds of clay and silt, but with groundwater at some depth below. In this case the likelihood of contaminants entering the groundwater system is lessened.

The volume of leachate produced from a landfill is primarily a function of the rainfall that enters the landfill. This means that the nature and condition of the surface covering (cap) is important, as this generally controls the hydraulic gradient through the landfill.

Figure 1: Groundwater Risk Ranking for Small Landfills

Insert Highest Applicable Value From Each Table

SOURCE

A) Quantity/Size → **0.4**

B) Mobility (Assumed High = 1) → **1**

C) Values for Toxicity

Age	Hard fill	Green	Municipal	Municipal +15% Industrial	Industrial
closed <15 yrs	0.2	0.5	0.6	0.8	1
closed >15 yrs and < 40	0.2	0.3	0.5	0.6	0.8
closed > 40 yrs	0.2	0.2	0.3	0.4	0.5

→ **C**

CONTAINMENT

D) Lining/Containment (No Lining = 1, Fully lined + gas & leachate collectors = 0.2) → **1**

E) Values for Protection of Aquifer and Effectiveness of Capping

Capping and Stormwater control	Permeability of Aquitard overlying Aquifer		
	Impermeable	Moderate	Free draining
Good	0.4	0.5	0.8
Moderate	0.4	0.6	1
Poor	0.7	0.8	1

→ **E**

PATHWAYS

F) Rainfall Values

Rainfall/annum	Value
<700mm	0.8
700mm - 2,000	0.9
>2,000mm	1

→ **F**

G) Values for Distance to Aquifer and User

Depth to aquifer	Distance to user		
	>300m	100m	<50m
0-3m	0.8	0.9	1
3-10m	0.6	0.9	1
>10m	0.5	0.8	0.9

→ **G**

RECEPTOR

H) Values for Beneficial Use

Beneficial Use	Value
Low	0.2
Irrigation	0.7
Stock water	0.7
Ecological	0.7

→ **H**

Potable	1

A x B x C x D x E x F x G X H	=	TOTAL RISK VALUE

Where: **High >0.5** **Med >0.2 to <0.5** **Low 0 to <0.2**

The protection afforded by capping will depend on:

- The nature of the materials used (clay provides good protection, gravels and sand allow high infiltration);
- Amount and type of vegetation on the surface (large tree roots can penetrate a cap and provide a pathway for rain);
- Thickness of the cap (usually a thickness of 0.6 m is considered the minimum) and the extent of capping (some closed landfills have not been capped, are incompletely capped or the cap has eroded);
- Shaping of the cap to promote runoff;
- Condition of the cap, as cracks and slumps or material which is easily eroded (e.g. sand) would increase the amount of rainfall likely to penetrate the cap; and
- Existence and operational effectiveness of stormwater cutoff drains to direct overland flow away from the landfill.

3.2.2 Assessment of Pathway

Rainfall

The volume of leachate produced is highly dependent on the rainfall that is able to enter a landfill. This means that in general, more leachate is produced from landfills situated in high rainfall areas than in low rainfall areas. The probability of contamination is therefore greater in high rainfall areas, since higher volumes of leachate also produce a greater hydraulic head (Figure 1). This hydraulic head will push the leachate through the landfill and into the receiving environment where containment is poor.

Rainfall values are available from sources such as NIWA, publications or local council information.[7] In assessing the likely magnitude of rainfall at a site, it is important that the specific location of the site is considered in choosing a suitable rainfall station for comparison. A very good example of the importance of comparing similar geography is on the South Island west coast where rainfall is about 3m/annum at the coast, rising to 6m/annum inland at the same latitude and within small distances.

Distance to aquifer and user

The depth and the distance to an aquifer affects the likelihood of contamination, and impact on the receptor. The depth of the aquifer and its distance from the user are considered key determining factors as physical and biological processes such as adsorption, diffusion, dispersion and degradation will occur during leachate transport through the aquifer (Figure 1).

3.2.3 Receptor

Beneficial use

Groundwater is a potential source for drinking water, irrigation and stock drinking water. The consequences of contamination by leachate is that the beneficial use of groundwater may be adversely affected. As the leachate plume migrates from the landfill, it will be diluted and dispersed. The closer abstraction is to the landfill site, the greater the risk that groundwater is contaminated.

The value for beneficial use is determined by the end user, as the water quality required for stock drinking water is of much lower quality than domestic drinking water (Figure 1). In addition, some groundwater is naturally of poor quality, due to land uses such as intensive farming or the geochemistry of the area, or insufficient quantities for use.

3.3 Risk to Surface Water

3.3.1 Containment

Protection of aquifer and effectiveness of capping

As for groundwater, the effectiveness of the landfill capping and storm water control at the site is key to the assessment of the volume of leachate produced from the landfill, and hence the risk of contamination to surface waters (Figure 2).

3.3.2 Pathways

Rainfall

Rainfall is a key factor as the greater the rainfall, the greater the volume of leachate produced, and the more likely it is to migrate off site (Figure 2).

Distance to aquifer and user

The closer a landfill is to a water body, the more likely it is that leachate will enter it through seepage. Conversely, the further away a landfill is from a surface water body, the more adsorption, diffusion and infiltration will occur as the leachate migrates. Landfills may also be located permanently in waterbodies such as a spring or a wetland, or leachate may discharge directly into a surface water body adjacent to the landfill or via drainage ditches.

Old landfills may be located within flood plains, or abandoned river channels so there is potential for a flood to cause erosion of the landfill's sides or cap. Inundation increases the volume of leachate during the period while floodwater is receding. Councils produce flood hazard maps that identify the risk of flooding in terms of frequency and this system is used to assign values to the likelihood of flooding.

While the distance to surface water bodies and the potential for flooding of landfills are separate variables, only a single value is to be selected for that parameter which has the greatest potential adverse impact.

3.3.3 Receptor

Sensitivity of receiving water

Most surface waters provide a habitat for aquatic organisms. Many Regional Councils require protection of aquatic organisms as a minimum water quality standard. The sensitivity of the surface water body to contamination by leachate will depend on the size of the water body (Figure 2). A large river is less sensitive to a discharge compared to a small stream, or spring.

Surface water can also be used as a potable water source. This would be highly sensitive to contamination. Other common uses such as stock watering and irrigation are less sensitive to contamination.

Figure 2: Surface Water Risk Ranking for Small Landfills

Insert Highest Applicable Value From Each Table

SOURCE

A) Quantity/Size → **0.4**

B) Mobility (Assumed High = 1) → **1**

C) Values for Toxicity

Age	Hard fill	Green	Municipal	Municipal +15% Industrial	Industrial
closed <15 yrs	0.2	0.5	0.6	0.8	1
closed >15 yrs and < 40	0.2	0.3	0.5	0.6	0.8
closed > 40 yrs	0.2	0.2	0.3	0.4	0.5

→ **C**

CONTAINMENT

D) Lining/Containment (No Lining = 1, Fully lined + gas & leachate collectors = 0.2) → **1**

E) Values for Effectiveness of Capping

Capping and Stormwater control	Value
Good	0.4
Moderate	0.7
Poor	1

→ **E**

PATHWAYS

F) Rainfall Values

Rainfall/annum	Value
<700mm	0.8
700mm - 2,000	0.9
>2,000mm	1

→ **F**

G) Values for Distance to Surface Water Bodies

Distance	Value
>50 m	0.4
<50 m	0.8
Drainage ditch from landfill	0.9
Within landfill	1

→ **G**

Choose only the highest value of G or H

H) Flood Potential

Flood frequency/years	Value
1 in 100	0.2
1 in 50	0.6
1 in 10	1

→ **H**

RECEPTOR

I) Sensitivity of Receiving Surface Water

Sensitivity	Value
Low	0.2
Moderate	0.7
High	1

→ **I**

A x B x C x D x E x F x (max of G or H) x I	=	TOTAL RISK VALUE

Where: **High >0.5** **Med >0.2 to <0.5** **Low 0 to <0.2**

3.4 Risk from Gas Accumulation

The hazards associated with gas are:

- Physical hazard of explosion from methane either mixing with air (oxygen source) or ignited by a spark (putrescible waste only);
- Toxic hazard from gases generated in the landfill. For a hazardous waste site, there may be potentially harmful significant concentrations of gases other than the traditional landfill gases.

Landfill gas is produced from the degradation of the organic material in the landfill. Initially the level of oxygen reduces and levels of carbon dioxide and hydrogen increase, as conditions in the landfill become anaerobic. As degradation progresses methane generation dominates. The length of time gas generation occurs, and the volume of gas produced is dependent on a number of factors such as the organic content of the waste, temperature and the presence of inhibitory compounds in the landfill.

The nature of the gas will depend on the type of waste received and the landfill age. Landfills that have taken hazardous waste or industrial waste are assigned the greatest value with respect to the potential for generation of toxic gas. Landfills dominated by highly putrescible waste such as from domestic sources or green waste are assigned the highest values for the potential for physical hazard.

Initially both types of hazards (physical and toxic) should be assessed to determine whether the greatest hazard is a toxicity or physical hazard (Figure 3). The greater hazard is then used for the risk assessment.

3.4.1 Containment

Lining/Containment
It is assumed that most small, closed landfills have no engineered containment, including leachate and gas collection and that the default value assigned is 1 (Figure 3). For a fully contained system a value of 0.2 is assigned.

Capping

The nature of the capping material (if present) will determine the likelihood for lateral migration. Use of a highly impervious capping material, such as clay, will increase the potential for gas to migrate laterally, hence a highly impervious cap has a value of 1 (Figure 3).

3.4.2 Pathways

Rainfall

Rainfall is important in that it will affect the rate of degradation and hence the volume of gas produced.

Foundation permeability

If the ground in which the landfill is constructed is more permeable than its surface cap, then gas may migrate laterally. Impervious materials such as clays will minimise the potential for lateral migration. Values can be assigned according to the permeability of the foundation (Figure 3).

3.4.3 Receptor

Contact with gas

Land use will determine the likelihood for direct contact via surface exposure. For example, there is higher potential for contact on an industrial site that has been developed near to a landfill, especially for maintenance staff who may enter service trenches. Conversely there is low likelihood of contact with gas in an agricultural setting, as the land is less likely to be disturbed without confined spaces (Figure 3).

Figure 3: Gas Risk Ranking for Small Landfills

SOURCE

Insert Highest Applicable Value From Each Table

A) Quantity/Size → **0.4**

B) Mobility (Assumed High = 1) → **1**

C) Values for Gas Generation

	Hard fill	Green	Municipal	Municipal +15% Industrial	Industrial
Toxicity	0.1	0.1	0.6	0.8	1
Physical	0.5	1	1	1	1

→ **C**

CONTAINMENT

D) Lining/Containment (No Lining = 1, Fully lined + gas & leachate collectors = 0.2) → **1**

E) Values for Capping

Capping	Value
Permeable	0.4
Moderate	0.7
Highly Impervious	1

→ **E**

PATHWAYS

F) Rainfall Values

Rainfall/annum	Value
<700mm	0.8
700mm - 2,000	0.9
>2,000mm	1

→ **F**

G) Values for Permeability of Foundation Materials (Potential Travel Distance)

Permeability	Value
Low	0.4
Moderate	0.7
High	1

→ **G**

RECEPTOR

H) Values for Likelihood of Contact with Gas

Land use	Value
Agriculture, parks, recreation	0.2
Schools	0.7
Industrial. Commercial	0.7

→ **H**

Maintenance workers	0.7
Residential	1

A x B x C x D x E x F x G x H	=	**TOTAL RISK VALUE**

Where: **High >0.5** **Med >0.2 to <0.5** **Low 0 to <0.2**

3.5 Risk due to Surface Exposure

Hazards due to physical contact with a closed landfill comprise:

- physical hazard from such things as sharps, and
- toxic hazard from ingesting contaminated material.

3.5.1 Containment

Absence/presence of cap

The absence of an engineered cap will increase the risk of surface exposure (Figure 4).

Effectiveness of cap

If a site is well capped and well maintained then the potential for surface exposure is low. If a cap is too thin, or there is significant slumping and cracking which is not rectified, then there is the potential for waste to work to the surface. Erosion of a sand cap by the wind or surf is another example of where it would be likely that waste would be exposed (Figure 4).

3.5.2 Pathways

Distance

As this is direct contact the value assigned for distance is 1. Rainfall is a key factor, as capping materials subject to high rainfall have a greater potential for surface erosion and hence the risk of surface exposure is high.

3.5.3 Receptor

Direct contact

The risk components which determine if anyone, or anything, comes in contact with the exposed material depends on the nature of the surrounding land use.

Figure 4: Surface Contact Risk Ranking for Small Landfills

SOURCE

Insert Highest Applicable Value From Each Table

A) Quantity/Size → **0.4**

B) Mobility (Assumed High = 1) → **0.2**

C) Values for Surface Exposure

	Hard fill	Green	Municipal	Municipal +15% Industrial	Industrial
Toxicity	0.1	0.1	0.6	0.8	1
Physical	0.5	0.2	1	1	1

→ **C**

CONTAINMENT

D) Absence (1.0) or Presence (0.5) of Cap → **D**

E) Effectiveness of Capping

Capping	Value
Good	0.4
Moderate	0.7
Poor/absent	1

→ **E**

PATHWAYS

F) Distance (Automatically 1) → **1.0**

G) Rainfall Values

Rainfall/annum	Value
<700mm	0.8
700mm - 2,000	0.9
>2,000mm	1

→ **G**

RECEPTOR

F) Values for Likelihood of Direct Contact

Land Use	Value
Commercial /industrial	0.2
Schools. Recreation, agricultural	0.7
Residential	1

→ **H**

A x B x C x D x E x F x G x H = **TOTAL RISK VALUE**

Where: **High >0.5** **Med >0.2 to <0.5** **Low 0 to <0.2**

3.6 Pathway Interactions

Where there is an interaction between pathways, e.g. groundwater entering a gaining creek, the potential risk is to the surface water. As in the RSS approach, the beneficial use of the surface water then becomes the beneficial use of the "groundwater pathway". This needs to be noted on the assessment.

3.7 Ranking of Landfill Site Hazards

The method for ranking individual sites against each other is to determine the risk for each individual hazard, and to select the hazard with the highest numeric risk value as being the dominant factor for individual landfill sites. Each of the four hazards that have potential to cause adverse environmental effects from small closed landfills are considered to be independent, as are each of the risk assessment components.

As for the RSS, in deriving the total risk value for each hazard type, individual risk assessment components are multiplied together, and therefore all eight components of the risk assessment need to be input to derive the total value. Each hazard is considered to have one of the following levels of risk on the basis of the completed total risk value (Table 1). The total risk values have been proscribed by the RSS system[2].

Table 1: Risk Assessment Ranking Values

Total Risk Value	Risk Assessment
0.5 – 1.0	High Risk
0.2 – <0.5	Medium Risk
0.001 – <0.2	Low Risk

4 Application of RASCL Method

The RASCL method has been tested by comparing the assessed risk for 12 landfill sites against site specific monitoring data for the purpose of method verification.

4.1 Landfill Site Selection

From information received from territorial authorities about closed landfill monitoring, 12 landfill sites were selected for inspection to provide information for the risk assessment. The key criteria for selecting landfill sites for risk assessment were that they:

- had a history of monitoring
- reflected different climatic conditions

Monitoring data records were collated and analysed to identify sites in different climatic conditions. Table 2 below shows overall characteristics of the selected sites.

Table 2: Characteristics of Sites used for Risk Assessment Verification

Site	Temperature	Rainfall	Size (m^3)	Monitoring Period	Monitoring*
A	cool	958	<10,000	1994-current	leachate
B	cool	958	4,000	1998-current	stream water
C	warm	2052	<1500	1997-current	groundwater
D	cold	2392	<10,000	1994, 2000-01	river
E	warm	850	<1500	1997-2001	stream water
F	warm	907	<10,000	1998-2000	leachate pond, wetland
G	warm	871	1800	1996-current	groundwater
H	cool	2392	10,000	1999-current	groundwater
I	cool	851	at least 15,000	1999-current	groundwater
J	cool	713	15,000+	1999-current	groundwater
K	cool	1015	2,400	1995, 1997, 1999, 2000	stream water
L	cool	1108	<15,000	1997, 1999, 2000	Leachate/creek (1 sample)

4.2 Verification of Method

The computed total risk values and risk assessment rankings for the 12 small landfill sites are given in Appendix 1 – Table 1. An example for two of the landfills is demonstrated in Table 3.

Table 3: Example of the Risk Assessment Process for Two of the Landfills Monitored

	Site	A				B			
	Hazard	Contam-ination of ground water	Contam-ination of surface Water	Gas accumu lation	Direct surface exposure	Contam-ination of ground water	Contam -ination of surface Water	Gas accumu lation	Direct surface exposure
Source									
	Size	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	Mobility	1	1	1	0.2	1	1	1	0.2
	Toxicity	0.6	0.6	1	1	0.6	0.6	1	1
Containment									
	Lining	1	1	1	n/a	1	1	1	n/a
	Cap absent/present	n/a	n/a	n/a	1	n/a	n/a	n/a	1
	Capping	0.4	0.7	1	0.4	0.6	0.7	0.7	0.7
Pathways									
	Rainfall	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Distance	0.8	1	0.4	1	0.7	0.4	0.7	1
	Flood erosion			n/a				n/a	
Receptor		0.2	0.7	0.2	0.2	0.2	0.2	0.2	0.2
Total Risk Value		0.014	0.106	0.029	0.003	0.018	0.012	0.035	0.005
Risk Assessment (RASCL)		Low	Low	Low	Low	Low	Low	Low	Low

While both landfills A and B indicate low risk for all four hazards, landfill A has the greatest risk to surface water and landfill B has the highest risk to gas accumulation. This is useful to know if money is to be spent to reduce the risk.

Typically, there is a good correlation between those landfill sites where monitoring indicates significantly elevated contamination levels and higher RASCL total risk values (Appendix 1- Table 2). Analysis of the monitoring data shows that in general, groundwater at small closed landfills is unsuitable for drinking water. Elevated metal concentrations restrict use for irrigation and drinking water, and at some sites nitrogen levels are very high (Appendix 2).

The monitored groundwater bores were in or at the edge of the landfills and leachate is therefore at its most concentrated. Although groundwater quality is likely to exceed drinking water standards, it would be highly unlikely that abstraction for drinking water would occur beneath a landfill. The distance from the site at which concentrations would be suitable will depend on the characteristics of the aquifer, and needs to be considered on a case by case basis.

Surface water may be impacted by increases in nitrogen and metals, but there is a lot of variation in the data, sometimes showing upstream concentrations being higher than downstream (Appendix 2). This means that surface water quality may naturally exceed guideline values upstream of the leachate discharge.

In summary the data indicates that small landfills are likely to have an impact on groundwater directly beneath the landfill, but no discernible trend is evident with respect to surface water quality. Application of the RASCL procedure ranks the hazards at each of the 12 small closed landfill sites as low risk, which is consistent with the monitoring data (Appendix 1).

The data on small landfill leachate, groundwater and surface water quality collated from over 75 landfills as part of this research report are displayed in Appendix 2.

4.3 Limitation of RASCL method

As noted in Section 3.1.1 (a), the value assigned for the quantity of a contaminant from small landfills is always 0.4. This means that the total risk value (Table 1) can never be greater than 0.4 and thus small landfills will always fall into the medium or low risk categories. This is probably reasonable when compared to risks posed by larger landfills, but Councils will need to be aware that landfills classified as medium or low risk, could in fact have a higher risk and may require more detailed assessment.

Where the computed total risk values due to each of the four hazard values differ significantly for an individual landfill site, it is advised that the site should be assessed more closely to determine if the risk assessment is consistent. This advice recognises that the proposed risk assessment method is a screening tool and is a guide only which may need further interpretation.

4.4 Relative Ranking of Small Closed Landfills

As pointed out above, because of the restriction of size, no small closed landfill can be ranked as high risk, and in fact none even ranked as medium (Appendix 1). However, on inspection of the total risk values presented, it can be seen there is a variation in the values of several orders of magnitude (Table 4).

Table 4: Total Risk Values for each Hazard

Ground water	Surface Water	Gas	Surface Exposure
0.134	0.141	0.176	0.029
0.121	0.12	0.05	0.011
0.12	0.106	0.039	0.006
0.117	0.106	0.039	0.006
0.11	0.094	0.035	0.006
0.078	0.086	0.035	0.005
0.069	0.085	0.035	0.005
0.029	0.074	0.035	0.005
0.018	0.06	0.032	0.005
0.017	0.045	0.032	0.005
0.014	0.03	0.029	0.003
n/a	0.012	0.022	0.003

As the default value for size is 0.4 (Secton 3.1.1 (a)), that number is therefore the highest total risk value that can be obtained. Scaling from that figure, risk assessment rankings could be revised from those shown in Table 1 to those shown below in Table 5.

Table 5: Revised Risk Assessment Ranking Values for Small Closed Landfills

Total Risk Value	Risk Assessment
0.2 – 0.4	High Risk
0.1 – <0.2	Medium Risk
0.001 – <0.1	Low Risk

From the figures presented in Table 4 above, five sites for groundwater, four sites for surface water and one site for gas, would classify as medium risk if the risk assessment rankings were classified according to Table 5.

5 Summary and Conclusions

Risk components for determining the risk to the environment and health from small closed landfills (<15,000 m^3 in volume) have been identified and tested for 12 sites using the RASCL method. The main hazards assessed were:

- Groundwater contamination
- Surface water contamination
- Gas (landfill gas or toxic gas)
- Surface exposure (ingestion or physical harm from sharps).

The risk assessment evaluated small landfills as presenting a low risk to the environment and health.

This assessment was compared with results from monitoring data. Surface water data for the 12 small closed landfill sites show variable effects on surface water, with no trends observed, i.e. the leachate did not generally appear to be causing aquatic guidelines to be exceeded.

Leachate contaminating groundwater beneath a landfill makes it unsuitable for drinking owing to the presence of elevated metal concentrations. Irrigation water quality guidelines were also often exceeded. A 10-30 times dilution for all but the indicator organisms would provide suitable quality water. As groundwater at the sites was not used in the immediate vicinity for drinking water or irrigation, the risk was assessed as being low.

The method is suitable for assessing the risk to the environment and health from small landfills. As the low risk values differ by 2 orders of magnitude (Appendix 1) it would be advisable that sites with higher values be assessed individually to confirm the low risk ranking. This is a screening tool and it may be that an extra site visit or some more information may be required to evaluate the risk component that is signalled in the risk assessment as being most sensitive. Also a constraint of the RSS is the limit on the default value used for contaminant quantity, making it impossible for a small landfill to be classified as high risk. Medium risk landfills should therefore be assessed very carefully. Also, analysis of the figures showed a large variation within the low risk category and if these were assessed using lower total risk values for risk assessment ranking, hazards at several sites would classify as medium risk.

Whilst the RASCL method identified the 12 small closed landfills used in this study as low risk (Appendix 1), it must not be generically concluded that all small closed landfills will pose low risk to the environment.

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APPENDIX 1:

APPLICATION OF RASCL METHOD

Appendix 1 – Table 1: Details and Results of Risk Assessment of 12 Closed Landfills

Site	A				B				C			
Hazard	Ground-water	Surface Water	Gas	Surface Exposure	Ground-water	Surface Water	Gas	Surface Exposure	Ground-water	Surface Water	Gas	Surface Exposure
Source												
Size	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Mobility	1	1	1	0.2	1	1	1	0.2	1	1	1	0.2
Toxicity	0.6	0.6	1	1	0.6	0.6	1	1	0.8	0.8	1	1
Containment												
Lining	1	1	1	n/a	1	1	1	n/a	1	1	1	n/a
Absence or presence of Cap	n/a	n/a	n/a	0.5	n/a	n/a	n/a	0.5	n/a	n/a	n/a	0.5
Capping	0.4	0.7	1	0.4	0.6	0.7	0.7	0.7	0.7	0.7	1	0.7
Pathways												
Rainfall	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1	1	1	1
Distance	0.8	1	0.4	1	0.7	0.4	0.7	1	0.7	0.9	0.4	1
Flood/erosion			n/a				n/a				n/a	
Receptor	0.2	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.7	0.7	0.2	0.2
Total Risk Value	**0.014**	**0.106**	**0.032**	**0.003**	**0.018**	**0.012**	**0.039**	**0.011**	**0.110**	**0.141**	**0.032**	**0.006**
Risk Assessment	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**

Site	D				E				F			
Hazard	Ground-water	Surface Water	Gas	Surface Exposure	Ground-water	Surface Water	Gas	Surface Exposure	Ground-water	Surface Water	Gas	Surface Exposure
Source												
Size	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	n/a	0.4	0.4	0.4
Mobility	1	1	1	0.2	1	1	1	0.2	n/a	1	1	0.2
Toxicity	0.6	0.6	1	1	0.6	0.6	1	1	n/a	0.6	1	1
Containment												
Lining	1	1	1	n/a	1	1	1	n/a	n/a	1	1	n/a
Absence or presence of Cap	n/a	n/a	n/a	0.5	n/a	n/a	n/a	0.5	n/a	n/a	n/a	1.0
Capping	1	0.7	0.4	0.7	0.8	0.7	1	0.7	n/a	1	0.4	1
Pathways												
Rainfall	1	1	1.0	1.0	0.9	0.9	0.9	0.9	n/a	0.9	0.9	0.9
Distance	0.6	0.8	0.7	1	0.5	1	0.7	1	n/a	0.8	1	1
Flood/erosion			n/a				n/a		n/a		n/a	
Receptor	0.2	0.7	0.2	0.2	0.2	0.7	0.2	0.2	n/a	0.5	0.2	0.4
Total Risk Values	**0.029**	**0.094**	**0.022**	**0.005**	**0.017**	**0.106**	**0.050**	**0.005**	**n/a**	**0.086**	**0.029**	**0.029**
Risk Assessment	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**n/a**	**Low**	**Low**	**Low**

Site	G				H				I			
Hazard	Ground-water	Surface Water	Gas	Surface Exposure	Ground-water	Surface Water	Gas	Surface Exposure	Ground-water	Surface Water	Gas	Surface Exposure
Source												
Size	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Mobility	1	1	1	0.2	1	1	1	0.2	1	1	1	0.2
Toxicity	0.6	0.6	1	1	0.6	0.6	1	1	0.6	0.6	1	1
Containment												
Lining	1	1	1	n/a	1	1	1	n/a	1	1	1	n/a
Absence or presence of Cap	n/a	n/a	n/a	0.5	n/a	n/a	n/a	0.5	n/a	n/a	n/a	0.5
Capping	0.6	0.6	0.7	0.4	0.7	1	0.7	0.7	0.7	0.7	0.7	0.7
Pathways												
Rainfall	0.9	0.9	0.9	0.9	1	1	1	1	0.9	0.9	0.9	0.9
Distance	0.6	n/a	0.7	1	0.8	1	0.7	1	0.8	0.4	0.7	1
Flood/erosion		0.5										
Receptor	1	0.7	1	0.4	1	0.5	0.2	0.2	1	0.5	0.2	0.2
Total Risk Values	**0.078**	**0.045**	**0.176**	**0.006**	**0.134**	**0.120**	**0.039**	**0.006**	**0.121**	**0.030**	**0.035**	**0.005**
Risk Assessment	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**n/a**	**Low**	**Low**	**Low**

Site	J				K				L			
Hazard	Ground-water	Surface Water	Gas	Surface Exposure	Ground-water	Surface Water	Gas	Surface Exposure	Ground-water	Surface Water	Gas	Surface Exposure
Source												
Size	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Mobility	1	1	1	0.2	1	1	1	0.2	1	1	1	0.2
Toxicity	0.6	0.6	1	1	0.6	0.6	1	1	0.6	0.6	1	1
Containment												
Lining	1	1	1	n/a	1	1	1	n/a	1	1	1	n/a
Absence or presence of Cap	n/a	n/a	n/a	0.5	n/a	n/a	n/a	0.5	n/a	n/a	n/a	0.5
Capping	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.5	0.7	0.7	0.4
Pathways												
Rainfall	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Distance	0.8	0.7	0.7	1	0.9	0.8	0.7	1	0.8	0.8	0.7	1
Flood/erosion		if dam fails										
Receptor	1	0.7	0.2	0.2	1	0.5	0.2	0.2	0.8	0.7	0.2	0.2
Total Risk Value	**0.120**	**0.074**	**0.035**	**0.005**	**0.117**	**0.060**	**0.035**	**0.005**	**0.069**	**0.085**	**0.035**	**0.003**
Risk Assessment	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**n/a**	**Low**	**Low**	**Low**

Appendix 1 -Table 2: Comparison of Results of Total Risk Values with Surface Water Monitoring Data

Site	Ground water	Surface Water	Gas	Exposure	Monitoring	No. samples	Comment on monitoring data	Causes of Exceedences in SW guidelines[9] for protection of aquatic organisms
A	0.014	0.106	0.029	0.003	Leachate	6	Leachate elevated nitrogen and conductivity compared to surface waters, but 10-100 less than large landfills.	
A	0.014	0.106	0.029	0.003	US & DS	5	No trends. Increase in SS (1), Faecal coliforms (3) and Nitrogen (1)	NS
B	0.018	0.012	0.035	0.005	US& DS	6	No trends. Change in pH > 0.2 units (1), nitrogen elevated (1).	
C	0.110	0.141	0.032	0.006	groundwater	4, 4 bores	Lead, iron manganese, and nickel are elevated, and would require 10-15 times dilution to be consistent with DW, pH <6.5 (1), cobalt, aluminium, iron and manganese exceed irrigation guidelines 10-30 times dilution.	
D	0.029	0.094	0.022	0.005	river	7	Small changes to ammonia, boron chloride, conductivity, change in pH either 0.2 more or less than upstream value. Greatest difference is - 0.56. Greatest nitrate increases is 0.03mg/l, upstream range is 0.8-0.16mg/l.	S. pH increases and decreases outside guideline value
E	0.017	0.106	0.050	0.005	US & DS	11	Small changes in ammonia, alkalinity, boron, BOD_5, calcium, chloride copper, and iron, lead magnesium, SS RDP, pH and sulphate. Nitrate has an average increase of 0.13mg/l. Enterococci has large decreases downstream, indicating other influences on water quality.	I. If phosphate is high, nitrogen may have an effect
F	n/a	0.086	0.029	0.029	Pond	4	Pond has good DO (7.8-9.5 mg/l) and low nitrogen. The pH is alkaline 8.4-8.9 (3 samples). Enterococci (1) and COD (1) can be high , but the source of these contaminants in the pond may not be leachate.	I. pH may be naturally alkaline
F	n/a	0.086	0.029	0.029	Wetland		Dissolved oxygen levels are as low as 5mg/l, pH is slightly alkaline 7.5-8.3. suspended solids and Enterococci can be high, but this is not necessarily from leachate as COD is very low 2.5mg/l (2).	I. Dissolved oxygen and pH levels may be natural

Site	Ground water	Surface Water	Gas	Exposure	Monitoring	No. samples	Comment on monitoring data	Causes of Exceedences in SW guidelines[9] for protection of aquatic organisms
G	0.078	0.045	0.176	0.006	Groundwater	BH2 (26), BH1 (7)	BH 1and 2 are unsuitable for irrigation owing to conductivity, boron, iron, lead and manganese. Aluminium (BH1 and BH2) and cadmium (BH1) and zinc (BH2) exceeded guidelines once. Dilution 10-30 times would provide sufficient dilution. Faecal coliforms are also too high for drinking water. For drinking water dilution of BH 2 10 times would be sufficient dilution.	
H	0.134	0.120	0.039	0.006	Groundwater	10	Chromium (1) and faecal coliforms exceed DW. While pH is low (<6.5), this is common with groundwater. Conductivity is suitable for irrigation.	
I	0.121	0.030	0.035	0.005	Groundwater	10	Cadmium (1) , chromium (3) and faecal coliforms exceed DW. While pH is low (<6.5), this is common with groundwater. Conductivity is suitable for irrigation.	
J	0.120	0.074	0.035	0.005	Groundwater	7	DW for arsenic is just exceeded (2) and faecal coliforms are present, which makes it unsuitable for drinking water.	
K	0.117	0.060	0.035	0.005	US & DS	8	Decreases downstream in ammonia (1), nitrate (2) BOD_5 (1) faecal coliforms (3) and SS (2) suggest some other source of contamination. No trends are evident.	I. Other source of contaminant may be important
L	0.069	0.085	0.035	0.003	Groundwater	6	Enterococci and faecal coliforms are present which makes it unsuitable for drinking water. Nitrate levels are also very high. As with many groundwater, pH is always <6.5	

DW = New Zealand drinking water standard; DO = dissolved oxygen , NS = Not significant, S= significant, I = Investigate

APPENDIX 2:

LEACHATE, GROUNDWATER AND SURFACE WATER QUALITY DATA COLLECTED FROM SMALL CLOSED LANDFILLS

Appendix 2 - Table 1: Leachate Quality of 8 Small Closed Landfill Leachate and 3 Large Operational Landfills

		Small closed landfills					**Large operational landfills**			
Parameter		**Average**	**Standard Deviation**	**Max**	**Min**	**Count**	**Redruth**		**York**	**Omarunui**
							Low	**High**		
Aluminium	g/m^3	0.53	0.85	1.5	0.02	3	0.05	7.9		0.06
Ammonia-N	g/m^3	4.5	6.9	22	0.01	17	0.13	400	290	428
Arsenic	g/m^3	0.008	0.007	0.019	0.001	6	0.004	0.17	0.14	0.019
BOD_5	g/m^3	12	11	36	2	8	14	>220	530	100
Boron	g/m^3	0.48	0.41	1.1	0.05	12	1.1	5.8	7.2	10
Calcium	g/m^3	42.4	18.5	63	27.2	3	36	370		95
Chloride	g/m^3	63	49	222	15	17	690	7300	410	2584
Chromium	g/m^3	0.02	0.02	0.05	0.00025	11	*0.05*	0.11	0.08	0.1
Conductivity	mS/m	83	48	220	20.3	19	308	2546		11450
Copper	g/m^3	0.015	0.031	0.098	0.0005	9				
DO	g/m^3	7.3	1.9	12	1	7				
SAT	%	78	22.5	117	58	5				
DRP	g/m^3	0.11	0.18	0.4	0.001	7				
ENT	cfu/100 ml	259	404	1300	2	10				
Filtered BOD_5	g/m^3	1.25	1.19	3	0.5	4				
Hardness	g/m^3 as $CaCO3$	50.5	73.6	156	0.025	4				
Lead	g/m^3	0.025	0.042	0.13	0.0001	10	0.089		0.02	*0.01*
Manganese	g/m^3	0.7	0.96	2.1	0.11	4	0.49	5.2	4.6	0.55
Nitrate-N	g/m^3	0.75	1.15	3.8	0.001	11	*0.01*	0.017	0.06	2.1
pH		7.0	0.95	8.9	5.6	19	6.5	7.7		8.5
Potassium	g/m^3	29.8	21.9	56	6	4	7.2	380	150	720
Sodium	g/m^3	35	17.8	50	10	4	20	4250	290	1360
Sulphate	g/m^3 as $SO4$	13	2.9	16	10.8	3	22	780	32	23
SS	g/m^3	98	150	390	5	8				
Temperature	0°C	15	3.3	20.4	9.7	16				
Zinc	g/m^3	0.05	0.07	0.27	0.001	15	0.1	1	1.6	0.6

SS =suspended solids, DO = dissolved oxygen

Notes on leachate characteristics

Leachate characteristics will depend on the volume and age of waste in the landfill. It is understood from our survey that 41 landfills closed in the last 15 years. The landfills in our survey were therefore likely to still be generating leachate. In the study monitoring data from 75 small landfills was evaluated. Only eight sites from our survey actually had data on leachate (Appendix 2 -Table 1). The average concentrations and standard deviations are given and compared with data from three larger landfills, namely Redruth, York and Omarunui. Where the standard deviation is very high compared to the average e.g. ammonia it is likely that the sample was contaminated, or in error. A minimum and maximum value is therefore also reported. Parameters with more than 5 data points are reported. Mercury and cadmium were analysed (twice and four times, respectively), and not detected.

Where there are no leachate collection facilities, the small landfill leachate is likely to have been collected from surface sources and the chemical characteristics are more oxidised than typical leachate e.g. more nitrate and less ammonia, pH of 7. Low BOD_5 concentrations are consistent with the landfills being in the methanogenic stage, which develops 3-12 months after placement of waste. Generally ammonia, BOD_5, and chloride are at least 100 times lower. Conductivity, sodium, potassium manganese sulphate and zinc are between 10 and 100 times lower and boron is 10 times less. Reductions in metal concentrations (arsenic lead and chromium) are not as marked, but these were often below the detection limit and therefore the average is elevated. Chromium is 2-5 times lower, with lead and arsenic being half the concentration of the larger landfills.

Appendix 2 - Table 2: Surface Water Quality at Small Closed Landfills- Summary of Difference Between Upstream and Downstream Stream Data

Parameter	Ecosystem Guideline 95% Species Protection[9]	US Average	Average difference	Stdev diff.	Count	Maximum difference
Aluminium g/m^3	0.055 (pH>6.5*)*	0.83	3.661	7.692	11	20.58
Ammonia-N g/m^3	0.7	0.19	-0.134	0.757	42	0.07
BOD_5 g/m^3	No value	1.7	0.038	0.536	21	1
Boron g/m^3	0.37	0.08	0.004	0.026	19	0.08
Chloride g/m^3		19	8.425	47.667	41	300
Chromium g/m^3	0.001 (Cr VI) ID Cr III	0.05	0.005	0.01	10	0.024
Conductivity mS/m	150	15	4.7	21	38	125
Copper g/m^3	0.014	0.004	0.002	0.006	19	0.018
DO g/m^3	N/A	9.1	-0.2	1.9	28	2.7
Enterococci cfu/100ml		694	3	267	25	703
F.Coliforms cfu/100ml	1,500	544	1399	5780	16	20500
Iron g/m^3	ID	0.8	2.4	7.8	15	28.2
Lead g/m^3	0.034	0.13	0.005	0.02	23	0.1
Magnesium g/m^3	N/A	3.2	0.3	0.5	10	1.6
Nitrate-N g/m^3	0.7	2.5	-0.1	1.0	30	1.6
pH	7.2-8.0, <0.2 change	7.18	-0.02	0.19	42	0.4
DRP	0.015-0.30	0.025	-0.006	0.018	22	0.005
SS g/ m3	<10% change	12.2	1.6	9.7	17	31
Sulphate g/m^3	N/A	7.5	2.9	9.2	12	26.9
Zinc g/m^3	0.008	0.06	0.04	0.09	18	0.22

DO = Dissolved oxygen, DRP = Dissolved reactive phosphorous, ID = Insufficient data, Stdev = Standard Deviation

Appendix 2 - Table 3: Summary of Groundwater Data from Small Closed Landfills

Parameter							Guideline Values		No of Exceedences	
	Unit	Average	Stdev	Max	Min	Count	DW	Irrigation	DW	Irrig-ation
Alkalinity	g/m³ as $CaCO_3$	97	26	130	45	15				
Aluminium	g/m^3	6	5	15	0.033	15		5		9
Ammonical- N	g/m^3	0.05	0.05	0.29	0.005	77		total nitrogen 5		
Arsenic	g/m^3	0.01	0.03	0.18	0.001	40	0.01	0.1	7	2
Bicarbonate	g/m^3	119	33	160	55	15				
BOD_5	g/m^3	2.7	2.8	10	0.3	44				
Boron	g/m^3	0.23	0.3	1.3	0.005	49	1.4	0.5		5
Cadmium	g/m^3	0.001	0.003	0.02	0.00005	47	0.003	0.01	5	1
Calcium	g/m^3	349	24	124	9.5	20				
Chloride	g/m^3	25	26	89	1	84	400	175		
Chromium	g/m^3	0.018	0.02	0.08	0.0005	52	0.05	0.1	4	
Cobalt	g/m^3	0.026	0.03	0.08	0.0005	12		0.05		2
COD	g/m^3	53	60	181	5	17				
Conductivity	mS/m	32	20	109	4	79		19.8-59.4*		7
Copper	g/m^3	0.04	0.07	0.33	0.0005	30	2	0.2		1
DRP	g/m^3	0.05	0.07	0.4	0.0001	47		0.05 TP		14
Faecal Coliforms	MPN/100mL	108	720	5400	0	58	1		39	
Hardness	g/m^3 as $CaCO_3$	96	30	140	35	11				
Iron	g/m^3	17	18	57	0.05	50	0.3	0.2	40	40

Parameter							**Guideline Values**		**No of Exceedences**	
	Unit	**Average**	**Stdev**	**Max**	**Min**	**Count**	**DW**	**Irrigation**	**DW**	**Irrig-ation**
Lead	g/m^3	0.04	0.05	0.20	0.0003	32	0.01	2	18	
Magnesium	g/m^3	3.9	0.8	5.4	2.8	15				
Manganese	g/m^3	1.3	2.8	14	0.002	26	0.5	0.2	8	17
Nickel	g/m^3	0.03	0.04	0.13	0.00005	26	0.02	0.2		
Nitrate-N	g/m^3	2.6	8.5	55	0	81	10	total nitrogen 5	4	
pH		6.56	0.5	8.1	5.18	86	>6.5		33	
Potassium	g/m^3	3	3	12	0.27	25				
Sodium	g/m^3	14	14	40	2.2	30				
Sulphate	g/m^3	29	27	140	2	56	ID			
TKN	g/m^3	0.9	0.9	2.7	0.1	26				
Zinc	g/m^3	0.2	0.9	7	0.001	56	5	2	1	1
TN		3	9	55	0	95		total nitrogen 5		5

* Upper value range for sensitivity needed. Mercury, nitrate/nitrite RDP not analysed

DW = Drinking water standards, Stdev = Standard Deviation, TN Total Nitrogen, BOD_5, COD = Chemical Oxygen Demand, DRP = Dissolved reactive phosphorus, TKN = Total Kjeldahl Nitrogen

Note: sheep and cattle have a guideline value lower than drinking water standard for copper 0.4, 1.0 mg/l, respectively,

Medium salt tolerant crops assumed